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Bragg grating photo-inscription in doped microstructured polymer optical fiber by 400 nm femtosecond laser pulses

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Abstract: In this paper, we report the manufacturing of high-quality endlessly single-mode doped microstructured poly(methyl methacrylate) (PMMA) optical fibers. Bragg gratings are photo-inscribed in such fibers by means of 400 nm femtosecond laser pulses through a 1060-nm-period uniform phase mask. Preliminary results show a rapid growing process of the reflection band. To preserve a good spectral shape, the photo-inscription process was limited to ~20 seconds, yielding an FBG reflectivity close to 40 %.

1. Introduction

Fiber Bragg gratings (FBGs) were first inscribed in step-index polymer optical fibers (POFs) in 1999 [1]. Since these first achievements and because POFs show different characteristics compared to silica fibers, many investigations have been conducted on FBG inscriptions [2,3] and on their sensing applications [4,5]. Although different polymer materials can be used to manufacture POFs, the most often encountered one is poly(methyl methacrylate) (PMMA). As a result of the low photosensitivity of pure PMMA [6], a photosensitizer is usually added in the fiber core to improve the performance [1-3,6-8]. Taking benzyl dimethyl ketal (BDK) [6,7] for example, the photopolymerization process starts in the core under UV light radiation at 325 nm and induces a positive index change. Another photosensitizer is trans-4-stilbenemethanol [2,3,8], whose isomer structure changes from trans to cis, resulting in a negative index change. However, additional dopants have to be added in the core and (or) the cladding to meet the single-mode fiber criterion [9], which limits the quantity of photosensitizers in the core. In order to achieve POFs more competitive for Bragg grating inscription, Sáez-Rodríguez et al. fabricated microstructured POFs (mPOFs) with only BDK doped in the core without any other dopants [6]. However, not only the doping process was time-consuming but also some bubbles appeared in the fiber core. Here, we report an improved fabrication process for BDK-doped mPOFs. Thanks to a higher temperature (~50 °C) environment, it took less time (35 minutes) to dope the core presenting a better cross-section uniformity after drawing. Finally, FBGs were inscribed by a femtosecond laser using the phase mask technique. The reflectivity reached 40% after ~20 seconds, confirming the good efficiency of the process.

2. MPOF fabrication

2.1 Selected hole doping

The doped mPOF drawn at DTU Fotonik was produced following several steps. During the first one, a commercial PMMA preform with a diameter of 60 mm was drilled allowing us to obtain a hollow three-ring hexagonal cladding structure with a hole diameter of 3 mm and a hole-hole pitch of 5 mm. Afterwards, the preform was drawn to the cane with a diameter of 5.5 mm with reduced hole dimeter of 300 μm. In the second step, all the holes except the center one were blocked by UV-glue at one end of the cane (Figure 1a), and then the other end of the cane was immersed in the solution of methanol and BDK with a ratio of 3.3:1 in weight contained in a glassware. Because of capillary force, the solution was sucked into the center hole but not absorbed into other holes as a result of the higher air pressure in the blocked holes. When the cane was vertical in the solution, the distance between the solution level in the glassware and that in the center hole is only 4 cm. Thus, for drawing convenience the doping length was increased by tilting the cane by a large angle (Figure 1b). Then the only unblocked hole at the end was UV-glued as well (Figure 1c). Finally, the cane was moved back to be vertical in order to be easily controlled for the following step. The solution length in the center hole almost remained because of the negative air pressure in the hole (Figure 1d). As a result, more than 10 cm of doping length was achieved, and meanwhile there was no solution diffusing into other holes or the cane surface. Thereafter, the setup was covered by a film to prevent the methanol evaporation and then it was put into the oven at 51.5 °C for 35 minutes. Compared to the room temperature, the higher temperature in our case greatly improves the diffusion speed [10].

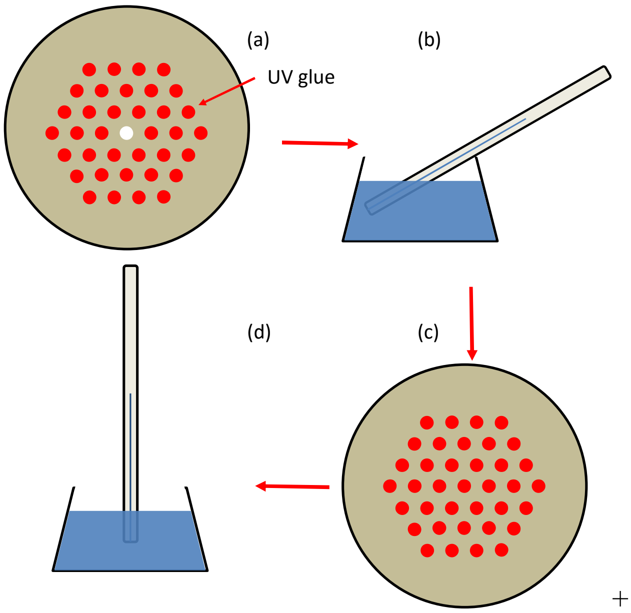

Figure 1. Scheme of BDK-doping preparation (all the holes blocked except the center hole at one end of the cane (a), the cane in the solution with a large angle (b), the center hole blocked at the same end of the cane (c) and the cane moved to vertical position (d)).

2.2 Preform annealing

In a following step, the cane was kept at 22 °C for 2 days and then annealed in the oven at 75 °C for two more days in order to make the methanol evaporate gradually to avoid the cracks generated on the hole surfaces. Figure 2 shows a cross-section image of the cane after these 4 days. The black area around the center hole is the BDK-doped PMMA.

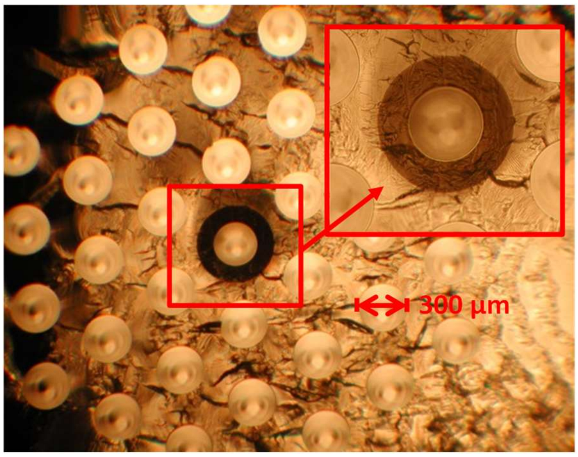

Figure 2. Cross-section image of the doped cane (4 days after doping).

2.3 Fiber drawing

In the last step, the cane was sleeved with several PMMA tubes to form a new preform, which was finally drawn to a mPOF. During the drawing process, the center hole was blocked by the BDK-doped PMMA by gravity, since the melting point of BDK (64 °C) is much lower than that of PMMA (160 °C). Figure 3 presents a perfect cross-section image of the fiber. The average hole diameter and pitch in the fiber are 1.5 µm and 3.79

µm, respectively. So, the ratio of the hole diameter to the pitch was calculated to be 0.4, confirming that the mPOF was endlessly single-mode. Since the diameters of the core and the cladding are 6 µm and 150 µm, respectively, this fiber can be easily connectorized with a standard single mode silica optical fiber.

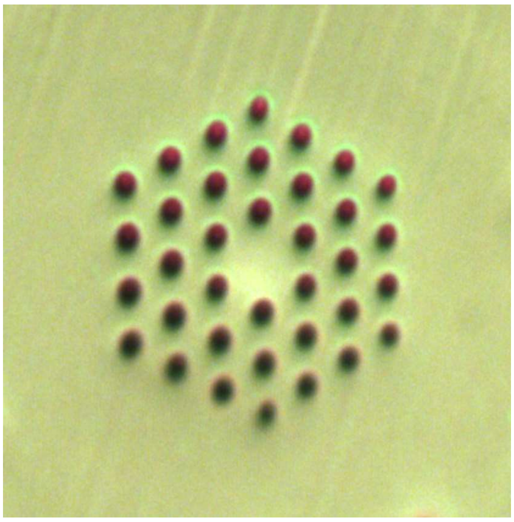

Figure 3. Cross-section image of the doped fiber.

3. FBG fabrication

After manufacturing the doped mPOF, the grating was inscribed at the University of Mons thanks to a femtosecond laser and a phase mask, both optimized to operate at 400 nm. The beam diameter was 6 mm with a power of 8 mW, which was tightly focused on the fiber core by a 5-cm-focal-length cylindrical lens. The experimental set-up is similar to the one used to inscribe grating in step-index POFs, as done in our previous work [11]. During inscription, the grating evolutions were recorded in both reflection and transmission modes, as shown in Figures 4 and 5, respectively. FBG reflection peaks appeared and grew gradually with a blue wavelength shift because of the accumulated heat from the laser. Although the grating spectra present a good shape in both reflection and transmission modes, the noise level in reflection started to increase dramatically after 16 seconds and the transmission losses grew at a rate of 0.1 dB/s. Hence, to keep a grating shape of sufficiently good quality, the photo-inscription process was limited to ~20 s. The corresponding FBG reflectivity has been computed equal to 40 %, which is by far enough for sensing applications. The aforementioned phenomena might be attributed to the BDK-doped core that, compared to pure PMMA, has a lower glass transition temperature (Tg) and a lower melting point. Thus, to produce gratings with a higher reflectivity, both laser power and inscription time should be optimised.

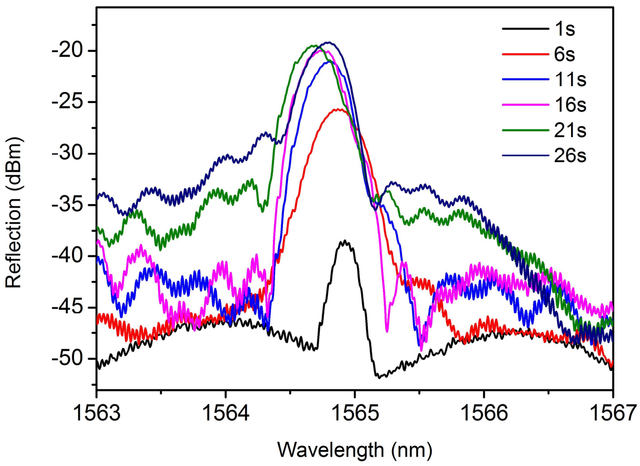

Figure 4. Evolution of the reflected amplitude spectrum during the photo-inscription process.

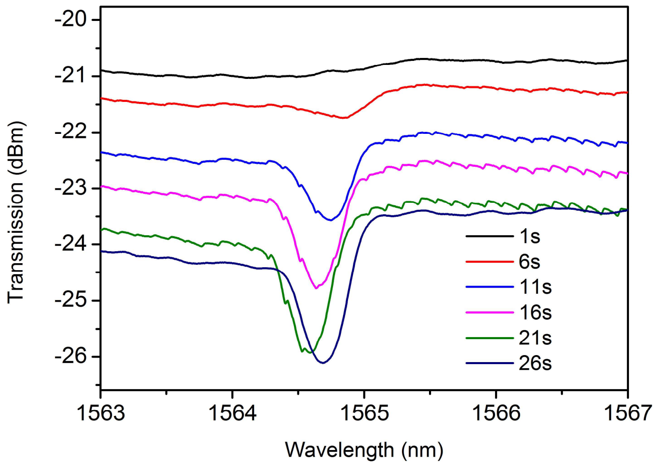

Figure 5. Evolution of the transmitted amplitude spectrum during the photo-inscription process.

4. Conclusion

In the first part of this paper, we reported the manufacturing of BDK-doped mPOF. Thanks to the selected center hole doping technique in the cane phase, the fiber was drawn with perfect cross-section image. In the second part, uniformed FBGs were photo-inscribed in the mPOF using 400 nm femtosecond laser pulses with the phase mask technique reaching saturation after 21 seconds with a reflectivity of 40 %.

5. Acknowledgements

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